

# Nanopillar Photovoltaics

## *A New Path to Cheap, Efficient, Flexible Solar Cells*

MSD's Ali Javey and his research group have demonstrated a new way to fabricate low-cost, efficient, flexible solar cells for the conversion of light energy to electricity. The cells consist of arrays of optically active semiconductors arranged as nanoscale pillars on aluminum substrates. The inexpensive 3-D photovoltaic (PV) array can be designed to maximize both light absorption and conversion efficiency.

Although the solar PV market is growing rapidly, it provides less than 1% of the country's electrical power. To increase the use of this clean energy source, mass production on a scale far greater than its current level is required. Unfortunately, the market leader today—PVs based on single and multicrystalline silicon—might not be economical in scale-up.

Solar cells use light energy to separate negative electrons and positive “holes” (absence of an electron), which then flow to electrodes to produce a current. Most current PV technologies are 2-D and use either wafer slices or thin films grown on a substrate. But different geometries have advantages. A 3-D nanopillar array offers more surface for collecting light than a 2-D cell. Further, computer simulations indicate that, compared to flat surfaces, nanopillar semiconductor arrays should be more efficient in absorbing light and have a greatly enhanced ability to separate electrons from holes and collect them as electrical current. However, early attempts to make PV cells based on pillar-shaped semiconductors have been disappointing, with light-to-electricity efficiencies of only one to two percent.

Javey's group devised a new, controlled process to make large-scale modules of dense, highly ordered arrays of single-crystal nanopillars. Electron rich cadmium sulfide pillars were grown on a template of anodized aluminum with geometrically ordered pores. A thin layer of hole-rich cadmium telluride was then deposited to cover the nanopillars. Electron-hole pairs are generated in the CdTe and the electrons flow down through the nanopillars to the aluminum contact below, while the holes are conducted to thin copper-gold electrodes placed on the surface of the CdTe layer. The efficiency of the test device was six percent, which, while less than the 10 to 18 percent range of mass-produced commercial cells, is higher than most photovoltaic devices based on nanostructured materials. Many feel that a device with 10% efficiency would be commercially viable.

The researchers worked to further enhance the versatility of the cell for potential consumer electronics applications. They made a flexible cell of the same design by etching away the aluminum substrate and substituting a thin layer of indium for the bottom electrode. They sheathed the whole assembly in clear plastic to make a device that could be flexed to conform to curved surfaces in devices, while maintaining its original level of performance,

The ability to grow single-crystalline structures directly on large aluminum sheets makes Javey's nanopillar arrays a promising path to versatile solar modules. In comparison to 2-D approaches, the 3-D configuration is inexpensive, making the requirements for quality and purity of the input materials less stringent. Further, higher efficiencies are clearly possible in the near future by, for example, increasing the transparency of the top contact above its current 50%, and increasing the density and the length of the pillars in contact with the window material.

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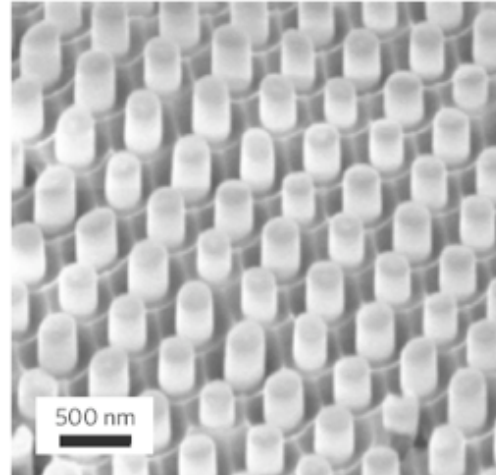
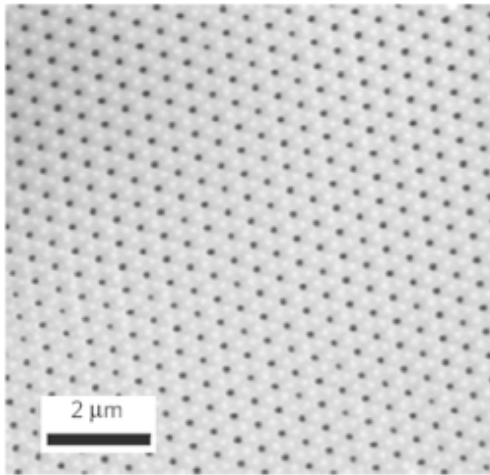
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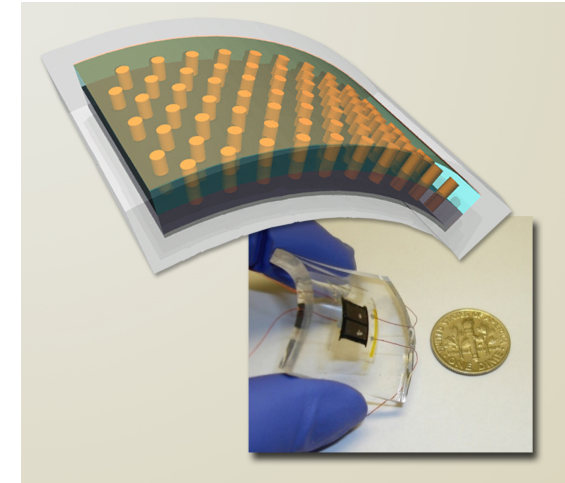
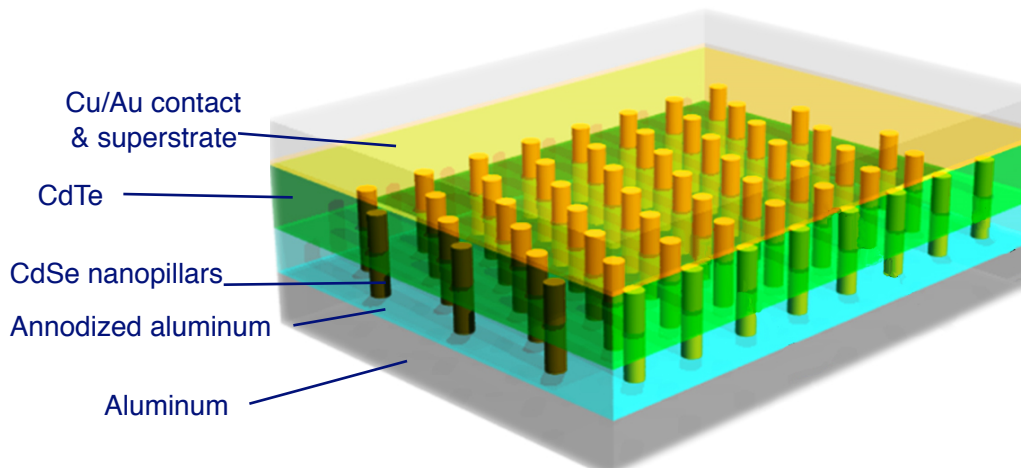
The solar-cell experimental characterization was done at LBNL, and was supported by the Helios Solar Energy Research Center, which is supported by the Director, Office of Science, Office of Basic Energy Sciences of the US Department of Energy under Contract No. DE-AC02-05CH11231. The nanopillar growth and solar cell fabrication was supported by Berkeley Sensor and Actuator Center, a National Science Foundation Industry/University Cooperative Research Center for Microsensors and Microactuators. We acknowledge G. F. Brown and J. Wu for help with simulations. J. C. H. acknowledges an Intel Graduate Fellowship. All fabrication was carried out in the Berkeley Microfabrication Laboratory.

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**Holes etched in an aluminum sheet (L)** serve as a template for the growth of a forest of cadmium sulfide nanopillars (R). The pillars (orange, below) are partially exposed and covered in clear cadmium telluride and equipped with a top electrode of copper and gold; the result is an inexpensive and efficient 3-D solar cell with a solar power conversion efficiency of 6%.



**The cell is made flexible** by substituting an indium bottom electrode for the aluminum, and embedding the 3-D array in clear plastic. The efficiency (below) is unaffected by repeated bending of the cell.

